PHYSIOLOGICAL AGE AND SCHOOL ENTRANCE

BY

ARTHUR K. BEIK

Clark University

A DISSERTATION SUBMITTED TO THE FACULTY OF CLARK UNIVERSITY, WORCESTER, MASS., IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY, AND ACCEPTED ON THE RECOMMENDATION OF WILLIAM H. BURNHAM

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Introduction

Child study has recognized in a general way alternating, or at least differentiated, periods of development, roughly classified according to predominant characteristics, physical and mental, and located with reference to the age of the child in years. Infancy is the term usually applied to the first year or years of life. Following infancy there comes the period of childhood, pretty sharply marked off at the later limit by the characteristics accompanying the attainment of pubescence.

The period of childhood is again variously divided by the different authors, the location of the division points depending upon the characteristics chosen as division marks. Because of the grouping of some important factors about those years at which school is usually begun, it is becoming more general to designate this as a natural division point, or perhaps better, nodal period, of development. The time preceding this nodal period is referred to as "earlier childhood," while the time from this to the appearance of pubescence is referred to as "later childhood." Later childhood, then, be-

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[1] Pres. G. Stanley Hall suggested the field in which to work out this thesis. The suggestions, advice and helpful criticism received from Dr. W. H. Burnham made its completion possible. For the helpful assistance from both these persons the writer wishes to acknowledge his indebtedness. He wishes also to express his thanks to those who assisted in the collection of material, among whom should be mentioned especially Dr. Theodate L. Smith and the library staff.

gins approximately at the time of entrance to the graded school and continues up to, or until a short time after, the completion of the graded school work, and might well be characterized as "the age of the grades."

The fact that it does so nearly coincide with the grade school years makes later childhood a most important period from the view points of child study and pedagogy. It is a period deserving of the closest study, especially as regards the child's development and his fitness to succeed in the tasks and cope with the new situations presented in the school environment.

Following a brief characterization of the developmental features at the close of this later childhood period, it is our intention to take up in this paper a somewhat more detailed discussion of those developmental features that group themselves about its beginning. It is our purpose to collect and condense available facts and data from the many investigations that have dealt with particular phases of development in these early years, to relate them in so far as is possible, and to suggest something of their significance.

What we have chosen to call the later limit of childhood is marked by those special phases of development that accompany the attainment of pubescence. It would be useless, for our purpose, to attempt a detailed description of these, though it may be worth while to mention a few of the more important points to which we may wish to refer later.

Very prominent among the physical changes characteristic of the pubescent period is that of growth, both in height and weight. Growth in height shows a remarkable acceleration, extending over several years. The average time for girls is from the tenth or eleventh to the thirteenth or fourteenth year, while for boys it runs from about the eleventh or twelfth to the fifteenth or sixteenth years. Most curves show a similar acceleration in weight following a little later, and occurring also a little earlier in girls than in boys. Both height and weight continue to increase for some time after this rapid acceleration, but at a slower and more uniform rate, so that boys and girls may be said to have almost reached adult size at the close of the rapid pubertal weight increase.

Closely related to these phenomena of general growth, occur rapid growth of certain parts and organs, rapid changes in body proportions, remarkable additions in muscular power, change in quality and increase in quantity of possible mental achievement, and, perhaps most important of all, the attainment of pubescence.

Dr. Crampton, *e. g.*, would seem to give the factor of

pubescence a place of prime importance, since he makes it the basis of grading for "physiological age" during this period (26).

Data with regard to time of eruption of the teeth seem to indicate a close relationship of dentition to the general stage of advancement of development. From tabulations of the number of canines and molars present, Crampton finds a definite correlation of tooth appearance and weight and of tooth appearance and height (26). The more extended investigations of dentition are of interest in this connection also. Boas and Wissler (11), Berten (8), and Röse (77) all found that the eruption of the teeth was earlier, on the average, for girls than for boys. Recalling the fact of earlier pubescence of girls, the suggestion of a relationship between pubescence and dentition, or perhaps better, the relationship of both dentition and pubescence to the general stage of advancement in development, is strong. There is a problem here worthy of further investigation. More knowledge of the relationship of advancement of dentition at this time to other factors of development ought to be very valuable.

Studies of the skeletal development, as worked out by Rotch (80), Pryor (70) and others, while not showing correlations for ossification of any particular part of the skeleton with pubescence, show in a general way a greater rapidity in girls at this stage of life. Great variability in degree of rapidity is also shown, especially by the work of Rotch and Smith (81) and also by that of Pryor indicated above.

Variability in the time of these developmental phenomena is everywhere evident. Tabulations of growth all show that the acceleration extends over several years. Variability is fully as great in dentition, as indicated by the tabulations for time of tooth eruption. Time of appearance of pubescence is also extremely variable. Crampton found this factor appearing in boys from 12.75 to 16.25 years of age.

These main facts concerning the developmental phenomena prominent at the pubescent period are sufficient to indicate that the actual limitation of childhood is not to be referred to a mere temporal reckoning of the length of life, but rather to development. They indicate also that this limit does not coincide with a definitely marked "time line," but rather constitutes a broad "time zone" within which the transition from later childhood over to the earlier stages of the adolescent period is accomplished. Within this zone, the variability is sufficiently great, as has been pointed out by Dr. Crampton, Rotch and Smith, Pryor and others, to render grading on the basis of chronological basis alone inadequate.

Finally, this stage of development is reached by girls earlier than by boys, as has been indicated by almost every study of development having to do with this period of life.

While the close of later childhood is thus pretty clearly marked off by prominent developmental features, there is not at its beginning such a clear cut and astounding transition. Those factors which may be used as marks of development are much harder to distinguish, and therefore to correlate. There is available, however, a considerable body of facts that may assist us in the solution of one or two of the most important problems that have to do with this period, and in the statement of some other problems that need solution.

Among the important problems are these two: (1) Is there, at the age of five or six or seven years, evidence of a transition or nodality of development comparable in any manner to the transitional stage at puberty? (2) Is the advancement in the two sexes equal at this period of life, and if not, how do they differ? We shall take these up in order.

Evidences of Nodality

The School Age.—Turning to the first of the problems just indicated, it may be worth while, before taking up the discussion of actual physical characteristics, to point out that this period of the child's life has for centuries been recognized in a practical way as transitional, in that it represented the time for the beginning of formal education. The actual chronological age differed somewhat with different peoples, but for the most part formal training, as distinguished from home training was begun at the age of six or seven years.

Of China, Douglass wrote (31, p. 165): "School life commonly begins at the age of six, and the youthful learner is at once set to learn by heart easy text-books which give in short sentences the leading principles of Chinese polity." Monroe states that in the old Greek period the Spartan boy was taken after seven years of training under the direct care of the mother and put under charge of assistants to the paedamonus, being cared for from that time on in public barracks at public expense (56, p. 74). Similarly, Athenian boys began attendance at school at about the age of seven years (56, pp. 82-3). Plato, in his ideal Republic would have the boys taught music and gymnastics from the age of seven on (56, p. 135). Medieval and modern education have fallen into line. The legal age for school entrance in most states, and in most countries also, at the present time, falls within the sixth or seventh year. Thus in the educational practice of most nations it has been found experimentally that at about this time of

life the child has reached such a stage of development that he can undertake the tasks involved in education of a formal nature.

If, now, we turn attention to the more tangible evidences of the stage of development, we are led to several considerations. There are the matters of growth, both in height and weight, dentition, growth of various parts of the body, including skull, brain, larynx, eye, etc. Another group of facts also, related both to neurological structure and to psychology may be added. These have to do with the neuro-muscular control of the child. Finally, a few suggestions may be obtained from the field of pathology.

Height and Weight.—As regards growth in height and weight, it is generally agreed that the closing years of the later childhood period are years of retarded growth. This conclusion is based upon the results of numerous extended investigations. Conclusions regarding the earlier years of the period are much less definite, partly because of insufficient data, partly because of a difficulty in interpreting the meaning of the growth curves for these years.

Burk, who summarized the available statistics up to the time of his study, 1898, writes as follows (17, p. 257):

"If now we turn to Table A of heights, taking, for example, the larger American studies of Bowditch, Peckham and Porter, we see that the rate of growth is somewhat rapid in the beginning, the sixth or seventh year, and decreases with fluctuations until about ten years in girls and twelve years in boys, when the prepubertal acceleration sets in. This general decrease is to be noticed in all the larger studies, though the year of the beginning of prepubertal increase varies a year or so. The same decrease in rate from six years up to the time of the prepubertal increase is to be observed similarly in the case of girls. Curves constructed from absolute annual increases show, as a rule, in this childhood period one or two pronounced fluctuations, but they do not occur with a regularity in all charts sufficient to be of assurance that their cause is certainly physiological and not merely statistical. Nevertheless, it will be observed that the curves are by no means regular. . . ."

Although pointing out thus clearly the irregularities in the curve for these early years, Burk goes on to conclude that, in the absence of determinative data, it is perhaps better to regard the period from about six years on as one of a general decrease in growth rate, with one or two minor fluctuations. The investigations of Combe, Landsperger and Carstadt, made upon a comparatively small number of children, but more upon an individual plan, are pointed to as justifying this view (17, p. 258).

Smedley, in the Chicago investigations, noticed something

of these irregularities in the early school years. Following his reference to the pubescent acceleration of growth, he writes (84, p. 32): "The charts seem to show that a similar but less well marked period of activity is present from the beginning of school life to the age of nine."

Englesperger and Ziegler (32, Bd. 1) found that of the children in the first year of school, those between the ages five years and nine months and six years were noticeably smaller, on the average, than those from six years and one month to seven years of age. The averages for these periods were:

	Boys	Girls
5 yr. 9 mo.—6 yr.=	109.65 cm.	106.25 cm.
6 yr. 1 mo.—7 yr.=	111.66 cm.	110.77 cm.

They found considerable differences in height at this period between half year, and even fourth year groups.

A tabulation comparing the weights of these periods showed that a smaller percentage of those under six years had gained than of those over six years of age. This was on the comparison of weights eight weeks apart at the beginning of school.

Stratz (86, p. 66), in Germany, on the basis of rather limited statistics, agrees with a former author, Bartel, in making the first four years a period of bodily "fullness," the years from five to seven, inclusive, a period of "stretching," or spurt of growth, and the years eight to ten a second period of bodily fullness, preceding a second spurt from the age of eleven to fifteen.

So far as available statistical material is concerned, growth in weight presents a condition similar to growth in height. Without giving the data these tabulations may be characterized briefly, and their indications may be stated. Most tabulations begin with the school age and continue from that time on, thus preventing comparisons with the years that precede. Usually, also, the number of data for the earliest school years are few in number. Again, statistics for weight present an added difficulty in interpretation because of the greater variability in this factor. So far as comparisons of absolute figures may be relied upon, there is only a continuous but variable increase in weight from year to year in the two sexes, up to the age of nine or ten, when a retardation occurs. Boys appear to be slightly superior, throughout the entire course.

There is slight suggestion of a spurt of growth in the beginning school years, but there is not sufficient evidence to establish the point. What is needed here is a collection of

more data, beginning with the lower years and continuing through the beginning school years. One cannot see in these studies of height and weight a definite proof of a characteristic of growth at this period. It is a fact, however, that from the larger investigations the results strongly suggest a slight acceleration. It is also to be remembered that most of the tabulations have paid attention to yearly age groups only. Much more accurate would be a comparison of age groups for fourth years or perhaps for months.

The rather indefinite studies of development, as indicated by increase in growth in height and weight, may be supplemented by some more definite facts with regard to individual organs or parts of the body that give more distinct evidence of a nodality at the school age.

Development of Teeth and Jaws.—The period with which we are here dealing is distinctly a transitional one as regards the development of the teeth and jaws. These present a number of phenomena, transitional as well as developmental in their nature, that group themselves about the years in which the change from first to second dentition occurs. Some of these are very evident, others less so, but altogether they make up such a group of developmental processes, so closely associated with each other, and also to other phases of physical and mental development that they deserve to be noted considerably in detail.

Aside from this, there are also other well grounded reasons for dwelling somewhat at length upon this topic. 1. Anatomically, the teeth and jaws are the most important structures in the facial part of the skull. Much of the remaining portion is of rather secondary nature, its purpose being to furnish place for attachment of muscles or to give proper bracing and support for these parts. 2. On the side of physiological functioning the teeth and jaws are extremely important. Upon them devolves a great part of the preparation of food in the process of digestion, not to mention the part they play in articulate speech. 3. Again, from the view point of hygiene, it may be said that columns of good, sound teeth, so located as to bring their chewing surfaces into proper occlusion, are requisites of good health. The absence of these conditions may lead to any of a number of allied disturbances, to which more detailed reference will be made later. 4. Finally, since they occupy so prominent a place anatomically, the form and general outline of the face are to a great extent dependent upon teeth and jaws. It therefore follows that from the view point of esthetics the proper formation and development of teeth and jaws may not be left unconsidered. Thus we may

say that from any of the four view points, esthetic, hygienic, functional or structural, development of teeth and jaws deserves the fullest consideration. We shall attempt to consider the topic from all four of these view points in the following paragraphs devoted to it.

While most concerned with the transitional phenomena, so much depends upon preceding and following developmental processes that a rapid review of the entire period of dentition may be of value in setting forth more clearly the characteristics of the transitional period. In this review, it is assumed that the reader's general knowledge of form, names, and composition of the teeth is sufficient to render detailed descriptions unnecessary. Since similar knowledge with regard to the jaws, on the other hand, seems to be less general, descriptions of the principal structures with which we shall need to deal will be included. For the sake of clearness, the facts with regard to development of the teeth will be presented first, then those with regard to development of the jaws. With these two groups of facts before us, we may next proceed to discuss their relationship and its significance, and arrive at some conclusions. With these hints as to method of procedure before us, we turn next to the presentation of the facts.

Although the eruption of the first or temporary teeth from the gums does not take place until some time after birth, the formation of their crowns begins very early in the developing embryonic jaw. Their calcification is already far advanced at the time of birth. The early formation and development of these is somewhat as follows: Above the gums, along the rudimentary jaw of the embryo, there is formed very early a ridge of epithelial cells. At each of the ten points at which a tooth crown is to be formed, a depression or invagination occurs in this ridge, pushing on downward into the jaw in a line, as it were, or tube, and expanding at the end into a bell-shaped structure,—the enamel organ. Gradually the enamel organ grows down over the top and sides of a small mound-like enlargement that rises up from the deeper tissue, —the dental germ. Again a little later the connection of the enamel organ with the epithelial ridge above is lost, enamel organ and dental germ together become isolated from the surrounding parts and enclosed in a "dental sac," and within this sac the two organs proceed to build up the parts of the tooth crown. Out of the soft cells that make up the enamel organ is formed the enamel; out of those of the tooth germ is formed the dentine or ivory of which the inner part of the tooth is composed, and within which, again, is the open cavity containing the pulp.

The transformation of these soft cells into the hard structures of the crown is accomplished by means of the deposition of lime salts within the cells themselves, and is usually spoken of as a process of calcination or calcification. The processes are not the same in both cases, however. While the cells of the enamel organ become changed into solid crystals, those of the dental germ receive the lime deposits only around the outside in such a way that the resulting structures are elongate tubes. The central, uncalcified portions remain as fine fibrils which are connected with the soft pulp of blood-vessels and nerves that fill the inner cavity of the tooth. The dentine tubes thus formed are of considerable length and extend outward radially from the pulp cavity to the enamel " roof " of the tooth.

The direction in which the calcification proceeds differs in the two organs. It will be remembered that the enamel organ folds over and encloses the dental germ. Now, the calcification begins at the contiguous surfaces of the two organs and proceeds in both directions. For the enamel cells, then, calcification proceeds from the inner surface toward the outer; for the dentine cells, it proceeds from the outer surface inward toward the pulp cavity.

Enamel and dentine differ also in another way. The enamel crystals receive no more nourishment after being once formed. The dentine cells, on the other hand, continue to receive some nourishment throughout the life of the tooth by means of the soft fibrils in the central tubular portions. (63. p. 31.)

As the development of a crown proceeds beneath the gums there is deposited around it a layer of bony substance, so that by the time it is completed it is almost enclosed in a bony case or crypt. The top of the crypt is open, though the aperture is not large enough for the crown to pass through without absorption of some of the tissue from its edges. This is what occurs at the time of eruption of the crown.

After the manner thus described there are formed ten tooth crowns in each of the jaws. Their calcification is not entirely completed by the time of birth, but it is completed within the first few months of life. Then they emerge from the gums to form the " temporary set " that functions during the early years of the child's life. Of these, the incisors and canines are small, as compared with the corresponding teeth that follow. The bicuspids, or milk molars, on the other hand, are larger than the permanent bicuspids that follow. In this way ample provision is made for the mastication of such

foods as the child is able to digest and assimilate during his early years.

Some weeks after birth the crowns of the temporary set are completed and begin to erupt from the gums. The first become visible at about the sixth to eighth month of life, usually, and at the age of about two and one-half to three years the child is equipped with a full set of twenty. Appearance is usually in groups, beginning with the central incisors and proceeding, in a general way, backward from these, with intervals of time elapsing between the several groups. Witzel reports the usual time for the eruption of these, as given by Thomas and Baume, to be as follows (98, p. —):

Central incisors	6- 8 mo.
Lateral incisors	6-12 mo.
Anterior bicuspids	12-16 mo.
Canines	15-20 mo.
Posterior bicuspids	20-30 mo.

The basis for this statement is not given, no mention being made of actual investigation. The periods given are those within which the eruption from the gums usually occurs. It is possible for the teeth to appear much later, however, and yet be normal. It is also possible for a few of the crowns to be already visible at birth and the teeth be normal, though this is very often the result of diseased conditions.

The process by which a tooth crown erupts is somewhat complex. The edges of the opening in the bony crypt must first be reabsorbed, making room for the crown to push through. The gums that form the covering are next absorbed. While this is going on and the crown gradually pushing upward, additions are made to the root from cells at the base of the crown, and, once the final position is attained, the root becomes fastened into place by the bony tissue built up around it. The root canal remains as a rather wide opening for some time, however, the dentine being built up gradually until the root is solid, except for the narrow canal through which the vessels and nerves are admitted to the pulp cavity.

The tissue built up around the teeth and within which their sockets are found is known as the alveolar border of the jaw or alveolar process. It is developed with the teeth and apparently for the specific purpose of holding them in position. Fuller description of it may be reserved until later. A description of the means by which the tooth roots are firmly fastened within it, however, is in place at this point. This can best be given in the words of Dr. Angle, taken from his paragraph on "Peridental Membrane" (1, p. 122).

"The peridental membrane is a strong, fibrous membrane forming a close, cushion-like investment of the roots of the teeth, and is the medium of attachment between the alveolar process and the cementum. It is composed largely of inelastic connective tissue, and is richly supplied with nutrient vessels, nerves, cells, and glands. Its function is three-fold:

"First, vital, for the formation of the alveolar process on one side and the cementum on the other.

"Second, sensory, through which the most delicate touch of the tooth is felt.

"Third, physical, holding the tooth in position in the alveolar socket, and resisting the movements of the teeth in the various directions. It also supports the soft tissues about the teeth."

Continuing, Dr. Angle enumerates the kinds of cells of which the peridental membrane is composed as, *1*, fibroblasts, for the formation of fibers of the membrane; *2*, osteoblasts, for the formation of the alveolar process; *3*, cementoblasts, for forming the cementum; *4*, osteoclasts, for disintegrating calcified tissue; and finally, *5*, glands, the function of which is as yet imperfectly understood (1, p. 123).

Malposition of temporary teeth is rare. When it does occur, it is easily corrected, under normal conditions, by means of the pressure from lips and tongue. But while this is true, abnormal conditions may as readily cause the teeth to be moved from their proper positions and thus bring about a malocclusion.

But the temporary crowns are not formed alone in the embryonic jaw. The beginnings of the permanent crowns are also present at a very early stage. Very early in the development of the enamel organ of each of the temporary teeth a second line or tube of epithelial cells pushes down by its lingual side. It appears as a branch of the tube which develops into the enamel organ of the temporary tooth. In structure, too, it is similar, and its development, later, after the manner described for the temporary tooth, results in the formation of the crown of the permanent tooth.

Aside from the ten corresponding to the crowns of the temporary set, there are also six other germs in each jaw, as the beginnings of the molars of the second set. The child at birth, then, has in each jaw the almost completed crowns of the ten temporary teeth and also the germs of the sixteen permanent teeth at various stages of development. The completion of the permanent crowns is of course later than that of the temporary, their time of most rapid growth, according to Pedley (62) being from birth to three or four years of age. Johnson places the critical period for their calcification at from birth to the age of five years, that of the first permanent molars having been begun even before the birth of the child (51).

The time of these processes is given more in detail by Witzel (98, p. 17):

> "The calcification of the crowns of the incisive teeth begins between the first and second year and the calcification of the canine tooth in the third year. In the fifth year of age the tuberosities for the second molar tooth are developed and in the ninth those for the third. About the time of the ninth year no remarkable processes of calcification take place in the crowns, except in the wisdom tooth, but the roots are not everywhere fully developed. . . ."

The ages mentioned are of course only approximate, and vary within wide limits.

From this it follows that from birth to about five years of age is a critical period for all the permanent set, except the wisdom teeth. During this period the dental germs, many of which have begun development at the time of birth, attain their final form, make their most rapid growth and undergo a great part of the process of calcification. In this connection it should be emphasized that when once formed and completely calcified, these crowns are adult crowns, as large as they will ever be, and subject to neither growth nor repair, so far as the organism to which they belong is concerned. Completion of the crowns is accompanied by enlargement of the alveolar border and growth in some parts of the jaw, with considerable redistribution of the inner structures.

Thus far we have noted the principal features in the formation and calcification of the temporary crowns, marked the important changes involved in their eruption and in their fixation into position by means of developing root structures and alveoli, and have traced the important steps in the process by which the permanent crowns are formed, developed and calcified within the alveolar portions of the jaws. Each one of these is a developmental feature characteristic of the earlier years, and constitutes a step in the preparation for the coming of the permanent teeth. The time immediately preceding second dentition is therefore a remarkable one for the child, considered from the view point of his dentition. Within his jaws there are *1*, a full set of twenty functioning temporary teeth, *2*, the practically completed crowns of their twenty successors, many of which are larger, *3*, the completed crowns of the four first permanent molars and practically completed crowns of the four second molars, and *4*, the only partially developed germs of four wisdom teeth or third molars. This is the normal condition of the child's jaws at the age of five or six years. Transition to the second dentition usually begins very soon afterward.

In discussing the eruption of the permanent crowns we may

first give attention to the time of their appearance, and then turn to the description of the process by which it is brought about.

Time of appearance of the permanent teeth has been made the object of a number of investigations. Some of these are of no value for our purpose, since they do not differentiate the sexes. Of the three available that do, one is not extended, but the other two are sufficiently so to make their results valuable.

First let us turn to the statistics of Boas and Wissler. Their material was a series of plaster casts taken from the palates of 219 boys and 276 girls. They therefore contain data for the upper jaw only. The following Table A is their table numbered "XI C." giving results in percentages (11, p. 34):

TABLE A.

Percentage of Children Having Permanent Teeth.

Age	Boys						Girls					
	In. Inc.	Out. Inc.	Can.	Bic.	1st Mol.	2nd Mol.	In. Inc.	Out. Inc.	Can.	Bic.	1st Mol.	2nd Mol.
6	30	4	....	....	65	....	38	9	6	15	83	2
7	40	6	3	3	83	....	79	28	2	41	92	....
8	81	26	....	19	100	....	84	48	9	45	93	6
9	97	67	....	30		7	100	59	9	45	100	2
10	100	63	33	66		3	94	82	14	73		8
11		95	61	100		9	96	96	73	83		20
12		100	85			38	100	100	86	100		32
13			91			68		88	88			68
14			100			66		90	90			90
15						75		100	100			100

Averages and variabilities were computed for the time of appearance of the several teeth and found to be as follows (12, p. 35):

	Boys	Girls
Inner incisors	7.5 ± 1.5 yr.	7.0 ± 1.6 yr.
Outer incisors	9.5 ± 2.1	8.9 ± 2.1
Bicuspids.	9.8 ± 1.6	9.0 ± 2.8
Canines	11.2 ± 1.4	11.3 ± 1.0
Second molars	13.2 ± 2.0	12.8 ± 1.6

TABLE B.

Age in Years	Sex	Number	Inner Incisors		Outer Incisors		Canines		First Premolars		Second Premolars		First Molars		Second Molars	
			Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
5.5– 6.	M	10	2	2	...	...	...	...	...	...	...	...	8	12	...	...
	F	6	...	...	...	...	...	...	...	1	...	...	...	4	...	...
6. – 6.5	M	42	...	13	...	...	...	...	...	...	...	...	26	50	...	...
	F	33	7	20	...	...	...	...	2	...	...	...	28	41	...	...
6.5– 7.	M	115	30	115	1	13	...	...	3	1	3	1	166	173	...	...
	F	140	50	147	4	33	...	1	3	3	2	...	211	242	...	...
7. – 7.5	M	97	44	145	3	26	...	...	1	...	...	...	179	182	...	...
	F	117	81	191	15	65	...	...	3	2	1	...	215	224	...	...
7.5– 8.	M	114	107	207	19	89	...	2	10	4	...	1	217	222	...	...
	F	119	174	224	47	116	1	2	15	3	3	...	233	233	...	...
8. – 8.5	M	101	157	194	55	125	...	5	21	3	2	3	193	194	...	...
	F	110	193	216	87	163	2	12	34	11	10	9	214	218	...	1
8.5– 9.	M	129	213	243	117	196	2	1	35	10	20	8	255	255	...	...
	F	117	217	229	145	189	9	17	62	28	17	15	233	232	...	...

9. – 9.5	M	124	228	243	167	220	1	17	72	32	21	15	**248**	**248**	...	...
	F	130	258	258	210	249	26	60	96	66	30	27	**260**	**260**	1	3
9.5–10.	M	134	262	266	239	259	9	27	111	57	48	34			1	6
	F	139	273	277	249	273	26	79	131	83	54	43			7	17
10. –10.5	M	115	**230**	229	207	227	18	34	107	70	59	44			4	8
	F	120	**240**	**240**	232	238	53	116	154	131	91	77			10	32
10.5–11.	M	112	**224**	**224**	209	222	35	68	136	86	92	51			14	36
	F	136	**272**	**272**	261	**272**	95	175	184	140	115	94			29	61
11. –11.5	M	119			227	**238**	70	137	140	127	109	73			26	62
	F	125			244	249	130	200	180	180	150	132			49	113
11.5–12.	M	116			227	**232**	83	149	181	144	133	91			46	74
	F	138			272	274	149	225	237	220	188	153			91	154
12. –12.5	M	128			253	**256**	151	110	222	210	189	151			127	161
	F	134			261	267	198	245	240	229	191	171			108	157
12.5–13.	M	97			193	**194**	132	165	181	160	150	133			113	145
	F	105			209	**210**	161	192	204	184	169	150			123	154
13. –13.5	M	59			**118**	**118**	94	106	110	98	104	95			91	105
	F	64			126	**128**	112	**128**	126	123	121	116			105	120

The investigation of Berten was much more extended. He collected data from some 3,345 children in Germany, of ages ranging from five and one-half to thirteen and one-half years. In the accompanying Table B are presented the numbers of teeth present for each half-year group within these ages. This table condenses the data found in Berten's tabulation (8, pp. 278-9). Boldface figures indicate groups where 100 per cent. were found present.

A report of an investigation much more extended than either of these appeared in recent years. Dr. Röse has tabulated the number of teeth found present in the several groups in case of 41,021 children in Germany, Sweden, Denmark, Holland, Belgium, Bohemia and Switzerland. His tabulation differentiates upper and lower teeth, also sex groups, and gives the averages and variabilities for the several tooth groups.

Table C is his "Table XIV," in which the results of the investigation are summarized (77, p. 564):

TABLE C.

ERUPTION TIME OF PERMANENT TEETH IN 41,021 SCHOOL CHILDREN FROM GERMANY, SWEDEN, DENMARK, HOLLAND, BELGIUM, BOHEMIA AND SWITZERLAND.

	Boys=21,139			Girls=19,882			
	Average eruption time		Eruption time varies between ages	Average eruption time			Eruption time varies between ages
	Yr.	Mo.		Yr.	Mo.		
UPPER JAW							
Incisor I...	7	8	5.5–11.5 Yr.	7	5	(–3 Mo.)	5.5–11. Yr.
Incisor II...	8	11	6. –(?) "	8	6	(–5 ")	6. –(?) "
Canine.....	12	2	7.5–15. "	11	7	(–7 ")	7. –15. "
Premolar I.	10	5	6.5–14. "	10	1	(–4 ")	6.5–14.5 "
Premolar II.	11	4	6.5–15. "	11	1	(–3 ")	7. –15. "
Molar I....	6	7	5. – 9.5 "	6	6	(–1 ")	5. –10. "
Molar II....	12	9	9. –15. "	12	5	(–4 ")	9. –15. "
LOWER JAW							
Incisor I...	6	10	5. –10. Yr.	6	7	(–3 Mo.)	5. –11. Yr.
Incisor II...	7	11	6. –12. "	7	7	(–4 ")	6. –12. "
Canine.....	11	2	7. –15. "	10	3	(–11 ")	7. –14. "
Premolar I.	11	3	7. –14.5 "	10	8	(–7 ")	7. –14.5 "
Premolar II.	12	0	7. –15. "	10	7	(–5 ")	7. –15. "
Molar I....	6	5	5. –10. "	6	3	(–2 ")	5. – 9. "
Molar II....	12	3	9. –15. "	11	9	(–6 ")	8. –15. "
Avg. of the total 14 eruptions.	9	10.0		9	5.4	(–4.6 Mo.)	

Careful study of these tabulations will show that they are in agreement as to the essential points regarding the time and the order of eruption of the permanent crowns. Each one confirms the prevalent view that transition to second dentition begins with the eruption of the first permanent molars. This is evident in the tabulation of Berten, and in the averages from the very extended investigation of Röse. Berten writes that in only three cases did he find the transition to the permanent teeth beginning before the appearance of any molars (8, p. 271).

Incidentally it should be noted that the time for the appearance of the first molars is in the seventh year. Berten's table indicates that practically all appear between the age of six years and seven and one-half, while Röse's averages all fall between the ages six years and three months and six years and seven months.

Again, the more extended investigations of Berten and Röse have furnished abundant evidence in confirmation of the view that the lower teeth appear, on the average, earlier than the upper, except, perhaps, in case of the canines and bicuspids. In all the investigations a considerable variation in the time of appearance for the several tooth groups is evident. From this it follows that dentition does not run a parallel course in all children. Variation in time of appearance is least in case of the first molars and grows progressively greater with each succeeding tooth group, up to the bicuspids and canines.

The order in which the permanent crowns appear is represented in these data. According to them it runs: first molars, inner incisors, outer incisors, first bicuspids, after which the order of the remaining groups is somewhat confused. Berten states (8, p. 274) that most often we find these groups appearing in such a way that the lower canine follows the first bicuspids, and is followed, in turn, by the upper second bicuspid; then the lower second bicuspid appears, and the upper canine brings up the rear.

Finally, before leaving this topic, the point of sex difference in time of eruption of the teeth should be pointed out. In each of the three tabulations it is clearly evident, beginning with the first molars, at the very beginning-time of second dentition. Röse's results show the girls to be two months earlier in eruption of lower first molars; one month ahead in eruption of upper first molars, on the average. The actual difference of time is not so evident in Berten's table because of the form in which it is presented, but comparison of the numbers of the teeth present show that the results would be

in agreement. Presented in the form of curves showing the percentages of teeth present in the various groups, Berten's data show very clearly that this is true.

The processes by which the eruption of the permanent teeth is accomplished deserve some further consideration. Evidently the temporary structures must first be disposed of. This is the first step in the eruption of the permanent set. It is accomplished by a sort of reverse process to that by which the temporary roots are builded down and fixed within the alveolar border. Beginning at the lower parts, the roots are again reabsorbed, along with the bony case of their sockets, even before the term of functioning of the teeth is completed. Radiographs showing partially reabsorbed roots present very much the same appearance as those showing partially developed ones. Apparently the reabsorption, or resorption, as it is often called, is incited by the pressure of the developing permanent crowns below. At any rate, in normal cases the process is sufficiently advanced by the time the permanent crowns are ready to appear to allow the temporary tooth to be readily removed with very slight disturbance and very little pain.

Evidently here are processes in which the different types of cells in the peridental membrane described above, especially the osteoclasts, play a very important part. Pedley and Harrison (63, p. 52) would credit the leucocytes with an important part in the resorption process also.

Aside from the resorption of the temporary roots there is also a process of resorption of the cancellated tissue that surrounds the deeply embedded crowns, allowing for their passage upward toward the surface. In case of the molars, this includes the absorption of part of the cortical bone along the borders of the jaws where there have been no preceding temporary teeth.

The growth process by which the crowns emerge, making additions to the roots while so doing, is not essentially different from that of the temporary ones already described. Building up of the roots seems to be a somewhat slower process in this case, and their final cementing into place more permanent. This latter is rather an osseous change and will be mentioned more in detail later, but it should be noted in this connection that the order is always first tooth position, then adjustment of foundation. This is true regardless of whether the position assumed is normal or abnormal. The bony foundation builds to the tooth, whatever may be the position it assumes.

Again, difference in size, especially of incisors and canines,

is greater in the upper than in the lower jaw, so that readjustment of the two columns of teeth to each other becomes necessary. This is a fact of considerable importance for the normal occlusion of the teeth of the permanent set. Whereas the upper and lower teeth of corresponding names fit end to end in the temporary set, in the permanent, the greater size of the teeth in the upper column cause a backward shift along the sides. The normal condition is therefore for each molar and bicuspid to articulate, not with a single antagonist in the other jaw, but with two teeth.

So much for the phenomena of dentition. The treatment is inadequate, but possibly sufficient facts have been presented in this brief review to indicate that the beginning of later childhood is without a doubt a transitional period as regards the teeth. Preceding this period time and material are both devoted to the task of providing temporary structures and preparing permanent crowns; with the eruption of the first molars at this period, however, is ushered in a series of remarkable changes, every one of which is a step in the direction of dental maturity. Dr. Port (65) stated the case nicely when he referred to this period of life as one at which, for the dentist, the child becomes adult. The significance of these phenomena becomes greater when they are associated with others closely allied to them, and, in a way, depending upon them. To some of these we shall next give attention.

Paralleling that of the teeth, there must occur a progressive development of the bony arches of the jaws that form their foundations. Structurally, both jaws are complex, and are in very close relationship to the other parts that make up the facial portion of the skull. Thus the upper jaw forms the principal bone of the face, taking part in the formation of the hard palate, the floor of the orbit and the floor and lateral wall of the nasal cavity (71a, p. 50). Cryer states (27, p. 31) that in a surgical operation removing a right or left maxilla, "the inferior turbinate, portions of the lachrymal, the palatal, the malar, and the ethmoid bones will probably be removed with it." The lower jaw, on the other hand, has the distinction of being the strongest and thickest bone of the face. It is made up of the arched portion known as the body, and the two ascending portions called the rami, each of which has a flat, pointed projection at its anterior edge for the attachment of muscles, and at the posterior edge a convex process which hinges with the forward portion of the temporal bone and allows for the movements of the jaw.

Leaving aside for the moment the details of structure, we

may generalize with regard to the arched portions of the two jaws by saying that in either case, the essential features are (1) a basal osseous arch composed of an outer shell of cortical bone filled in with spongy, cancellated tissue, and (2) an alveolar border consisting of two thin, hard, compact plates, an inner and an outer, fitting close to the roots of the teeth, between which is the looser cancellated portion surrounding the roots of the teeth, and within which the more compact, shell-like cases surrounding the roots are contained. The whole arrangement of the jaws, both with reference to each other and to the remaining portions of the face and skull, is such as to withstand the strain of muscular contractions in chewing, and at the same time protect against forces from without, such as blows, by diffusing them in a way to prevent their being transmitted to the brain case (27).

As already intimated in a previous paragraph, the development of the jaws begins very early in the embryo. According to Quain's Anatomy (71), the order for the beginning of calcification of the bones is : first, the clavicle; second, the inferior maxillary (mandible); and third, the superior maxillary (maxillae). The Text-Book of Cunningham places the beginning at about sixth or seventh week of foetal life (28, pp. 144-5). Witzel would seem to agree as to time, since he published a plate (98, plate 3), showing calcification of the mandible in a foetus of six weeks.

In case of either jaw, calcification begins in a number of centers which later unite. The final completion of this process does not occur in the mandible until some time after birth (usually during the course of the first year), when the two halves unite.

Extended and accurate investigations of the growth of the jaws from this time until the beginning of second dentition are very few. On a few points, however, authorities seem to be in agreement, so that we may characterize in a general way the principal developmental features of this period. Naturally we turn first to longitudinal growth. After the completion of the first year, or at least after the completion of first dentition, there is little or no growth in those portions of the arches containing the temporary teeth. If any occurs at all it is very small in amount. With the appearance of the teeth there is a lengthening of the ascending portions of the lower jaw, thus making room for the teeth and their alveolar borders. The relationship of this development to the order of the appearance of the teeth constitutes one of the nice adjustments of nature, as Pedley and

Harrison (63, p. 42) have pointed out. In general, the order of tooth appearance is from front to back. By this means time is gained for the growth in the length of these branches, while at the same time there is not left an "open bite" in the middle of the arch.

As regards internal structure, arrangement of the fine bony particles or trabeculae remains for the most part regular, though there are some changes having to do with strengthening the jaws and adjustment to the developing crowns of the permanent teeth (98).

The rapid growth of the jaws at the time of second dentition is a well known fact. It is evident in the changed proportions of both jaws and face, with the resulting change in facial expression, and is also inferred from the fact that the second set contains a greater number and, to all appearances, larger teeth.

Growth is largely dependent upon the development of the teeth, and is therefore not uniform in all parts of the jaws. A number of investigators have attempted to answer the question as to whether there is any longitudinal growth in those portions of the arches bearing the temporary or deciduous teeth at the time of second dentition. Zsigmondi (106) reports the results from a long series of these investigations, and in addition describes an investigation of his own, in which, by the use of plaster casts, he employed a new method, obtaining records of the same jaws at different stages of their development.

Difficulties of method are everywhere apparent, not the least of which is that the measurements give a record, not of the differences in the basic part of the jaw, but rather of those in the dental arch or the alveolar border only. Referring in part to the results reported by Zsigmondi, in part to the original articles themselves, and comparing carefully, it seems only safe to say that there is not conclusive evidence that any longitudinal growth occurs in that portion of the alveolar arch lying between the first permanent molars during the period of second dentition. Since this is true, there is likewise no evidence to show that longitudinal growth occurs in the basic portions.

That the dental arch in the upper jaw becomes larger is not disputed, but attention is called to the fact that here the teeth with their alveolar border slant outward, while in the lower jaw they slant rather inward, so that the question of longitudinal growth of the basic part of the jaw is still left unanswered. Besides, the question as to the presence or absence of growth is most often raised with reference to the

lower jaw, the result being that most investigations have had to do with it, and have secured data pointing more or less to conflicting conclusions. However, while conclusive proof is lacking, there is not general agreement that growth does not occur. More recently Cryer (27, p. 14), who bases his conclusion upon the study of the anatomical arrangement of the inner structure of the mandible, has declared in favor of growth. Angle also seems to hold this view (1, p. 91).

While growth in the "deciduous arch" is still questioned, on one other point authorities are agreed. While the permanent incisors and canines require a greater amount of space than their predecessors, the greater requirement is partially compensated for by a lesser space requirement on the part of the permanent bicuspids, which are smaller. The actual need for growth in these portions of the jaws is therefore much less than it would be were the permanent teeth uniformly larger than their predecessors. The compensation is much less nearly complete in the upper than in the lower jaw, thus giving a second partial explanation of the fact that the upper permanent dental arch is apparently larger, while the increase in the size of the lower is questioned.

Let us turn attention next to the posterior portions of the jaws. It should be noted first that authorities generally agree that growth of these portions is dependent upon the development and eruption of the molar crowns. In either jaw the growth must be sufficient to make room for the three molar teeth on each side. The development of these crowns seems to be the signal for growth of this portion of the jaws. This is especially noticeable in the lower jaw. "The cutting of the first molar tooth and the formation of the crown of the second cause in the following years of life a strong longitudinal growth of the maxillary body, . . ." writes Witzel (98, p. 59).

As in case of the anterior portions of the arches, there is much disagreement as to the exact process by which the increase is brought about. Some authorities, such as Cryer, hold that growth is general along the jaw and that each erupting crown pushes the ones anterior to it forward (27, p. 14). Others take the position that the growth is only at the extreme posterior portion, and that much of it is due to absorption and deposition of the bone substance. Humphry quotes Tomes (48, p. 3, footnote) to the effect that these processes are shown by the examination of the histological structures at time of growth. Humphry also tested the growth in the lower jaws of young pigs by piercing the ascending portions and tying wires about the anterior and posterior borders. Later, when the pigs were killed, the wires at the anterior

border were found to have either become loosened or dropped out, showing that resorption of bone had taken place, while the wires at the posterior borders were found in deeply indented notches formed from the progressive deposition of bone above and below them (48, p. 3 ff.).

Besides the horizontal growth in the arches of the jaws, adjustment to the greater space required between them to accommodate the larger permanent set is accomplished by means of a growth in the length of the ascending portions, or rami, of the mandible. With the longitudinal growth downward and backward the angle of the jaw becomes more acute, approaching a right angle, though this is apparently due in part also to the development of the teeth and alveolar border.

Finally there may be mentioned a group of changes of inner structure. Rearrangement of the teeth brings about a necessary redistribution of their neural and vascular supply. Increase of masticatory surface, accompanied by a growth in strength of the muscles used in mastication, causes a strengthening of the basic portions of the jaws; lastly, as a result of rearrangement of the lines along which the forces are exerted in mastication, as well as of growth, there occurs a new arrangement of the bony trabeculae within the jaws to adapt to the new conditions.

In addition to that of the jaws, some other developmental factors appear to be very closely related to dentition. Possibly most prominent among these is the growth of the face, due in part, of course, to the increasing size of the jaws. West found in his Worcester investigation (97) that there are pretty distinct periods in the development of the female face, the first division point being at about the seventh year. Transitions from one type to the one next following seemed to be rather abrupt. Röse found from head and face measurements of more than 45,000 children of different nationalities that the face lengthens much more rapidly during the time of change of teeth than it does in later years (75, p. 711). Facial index increased in length some three and one-half degrees between ages seven and thirteen (75, Table 5, p. 706).

Greater masticatory ability seems to be accompanied by an inner psychic change. Bell (7) found in his study of the psychology of foods that taste becomes "mentalized" at about the age of seven as it has never been before. He speaks of this as a stage of "teasing to taste." He found also a tendency to make every possible mixture at this period, and an increased interest in medicine, with a tendency to taste it.

Dr. Wright (100) finds that periods of enlargement of the

tonsils without inflammation coincide with the times when the groups of molars are erupting. He finds that after giving the tonsil prophylactic treatment, when necessary, and waiting for the tooth to erupt, the return of the enlarged tonsil to the normal will follow in a high percentage of cases. Disappearance of abnormal tonsilar conditions also follows the treatment of carious teeth in many cases.

He contends that tonsilar enlargement without infection is but an expression of the normal functioning of lymphoid tissues in that region, especially active at times of tooth eruption because of additional requirements in the way of caring for waste material which results from rapid bone resorption, etc. The second period when this condition is liable to be present coincides with that for the eruption of the first permanent molars, and therefore in a general way also with the period of life in which we are here especially interested.

One hesitates to leave this topic without dwelling for emphasis upon the importance of dentition for development at the beginning school age. Referring to the relationship of the teeth to nutrition, Crampton (26, p. 354) has spoken of tooth appearance as "the indication of successful growth and the earnest of further preparation for growth."

Again, importance of dentition stands out clearly when one takes into account the number of conditions by which its progress is affected. The great variation in time of appearance has been noted. There are many explanations for this. Early or late dentition have often been charged up to heredity, and facts regarding the first set, such as those presented by Holt (45, p. 28) and Rosenhaupt (79) would seem to indicate that there is reason for doing so. Röse has found that permanent teeth appear earlier among Swedish than among German children, thus showing the influence of race (77). He would also credit the chewing of coarser foods with some influence in this case. Again, in the same investigation, Röse found dentition earlier in children of the higher schools than in those of the Volkschule, and earlier in children of city than those of rural communities. This is explained as due to differences of nourishment, and to some extent to better racial selection also. The importance of nourishment while the crowns are developing, therefore during the first five or six years of life, is emphasized by many authorities. Bell (7), without giving his authority, states that it is reported southern children erupt their teeth earlier than northern. Finally, it is recognized that diseases influence dentition. Holt (45, p. 28) says syphilitic children are prone to early dentition, in which case rapid decay is likely

to follow. Rickets is usually credited with having a retarding influence. Röse tested this (77, p. 569) by comparison of children with normal teeth and those with hypoplasia, or deficiency of enamel. Among 10,020 children, he found a slightly later eruption time in the latter group. Latest dentition is seen in cretinism (45, p. 29).

The complexity of the problem is evident. Berten says (8, p. 267) that whoever has given only slight attention to the eruption of the teeth will have found that the time varies with race, climate, sex, constitution and disease, and in part to sports of nature.

Composition of the tooth crowns is apparently affected by many of the same influences, especially conditions of nourishment and disease. Lack of lime in food and water may cause poor dental structures, with deficient enamel, and therefore poor protection. Dr. Burnham (18, pp. 296-7) reports a number of investigations indicating that regions poor in lime show a high percentage of carious teeth. Pedley and Harrison (63, p. 47) emphasize the use of the teeth as beneficial, in that it increases blood supply and thus brings more nourishment. The disease of rickets apparently deprives the teeth of sufficient lime salts, being accompanied usually by hypoplasia, a condition in which the enamel is deficient.

Finally, we may cite the response of the organism to dental conditions, as evidence of the importance of the latter at the school age. Among others, Jessen (50, p. 1) quotes these conclusions from Röse's "*Zahnverderbniss und Zensur*" (*Deuts. Monats. f. Zahnheilk.*, 1904):

"*1.* The physical development of school children is greatly influenced by defective teeth. *2.* The poorer the physical development, the poorer also is the mental power ("Spannkraft") of the children. *3.* The poorer the teeth, the worse are, on the average, the grades of the children." In his article on the "Hygiene of the Teeth" Dr. Burnham writes (18, p, 298): "Of the various disorders frequently caused or aggravated by decaying teeth are not only enlarged glands of the neck, headache, neuralgia, earache, but indigestion, heart trouble, irritation of the nervous system, epilepsy, and perhaps chorea and other neuroses."

Preservation of a full set of sound temporary teeth and regulation of their positions when necessary are requisites for proper development of both teeth and jaws at time of second dentition. Premature extraction, too long retention, caries or malocclusion in case of the temporary set may be the cause of improper development of the jaws with impaction or with abnormalities in position of the permanent crowns.

Some experiments upon animals would seem to indicate the dependence of proper development in jaws and face upon a full set of functioning teeth. Walkhoff (92) cut one temporal muscle of a dog four weeks old, compelling him to chew only on the other side. Within three months a difference between the development of the two sides of the jaws could be detected, and at the end of a year the functioning side was much larger and stronger than the other. Dr. Baker (5) performed a similar experiment by grinding the teeth of young rabbits, preventing occlusion in one-half of the jaw. Not only the jaws, but the parts of the skull to which the muscles of mastication were attached showed the effects by their greater size and strength on the functioning side. The unused sides remained undeveloped. The prepared skulls showed a distinct asymmetry.

While emphasizing the point that the presence of all the teeth is essential, Dr. Angle has stated (1, p. 17) that, "in function and influence some are of greater importance than others, the most important of all being the first permanent molars." He explains further that this is true because, *1.* they are largest and firmest in their attachment, *2.* they have the most important location in the arches, *3.* their length determines the separation of jaws and length of bite, thus contributing to facial proportions, *4.* they are first in position and influence other tooth positions, and *5.* they are most constant in time of eruption and in the assumption of normal positions.

From all these facts, and especially in view of the close relationship of tooth development and nutrition, it must follow that dentition is a matter of prime importance in the early years. It would perhaps not be too much to say that, from among all the factors which may and should be considered for such a purpose, dentition is the best single indicator of the stage of physical development which a child has reached at any time during these early years, or, as some would state it, of physiological age.

Having dwelt somewhat at length upon this very important phase of development, we may bring together the principal points in this brief summary:

1. The development of the teeth and the parts closely related to them, particularly the jaws, give evidences of a transitional stage at about the time of the beginning school years. The loss of the temporary and the eruption of the second, permanent, more numerous, adult-sized set of teeth is begun at this time, producing a new, different method of

articulation. This is accompanied by rapid growth in certain portions of the jaws, with considerable rearrangement of the inner structures, resorption and deposition of bone substance, etc.

2. Normally, the transition is begun by the eruption of the first permanent molars, at about the seventh year, after which temporary tooth groups are replaced by the permanent in the order; inner incisors, outer incisors, first bicuspids, with canines and second bicuspids following in variable order, and followed in turn by second molars. Wisdom teeth come much later.

3. The time of tooth appearance in different children shows considerable variability, beginning with the early years, clearly evident at the time the first molars erupt, and increasing rapidly with the progress of dentition thereafter.

4. Sex differences are apparent in the eruption time of the permanent teeth, those of the girls appearing earlier, on the average, than those of boys. Here also, the difference increases with the progress of dentition.

5. The vital significance of dentition as a factor in development is shown by its close relationship to nutrition, by its close relationship to the growth of other parts, such as jaws, face and skull; by the many influences, such as nutrition, race, sex, etc., by which it is influenced; and by the reaction of the organism to dental conditions as shown in physical development, mental power, and the like.

6. These things being true, it follows that the state of advancement reached in dentition is a good indication of the stage of progress which a child has reached in his total physical development. The transitional features described therefore take on an additional significance.

Growth of the Skull.—The period of life under consideration is apparently transitional as regards the growth of the skull. In Quain's Anatomy (70, p. 82) we read:

> "The skull grows rapidly during the first seven years of life. By that time, certain parts, including the circumference of the occipital foramen, the body of the sphenoid, the cribriform plate, and the petrous division of the temporal have attained their definitive size. The other regions also increase but little until the approach of puberty, when a second period of active growth begins, affecting especially the face and frontal portion of the cranium, with which is associated the expansion of the frontal and other air sinuses."

These facts become the more interesting when we recall that cessation of growth in these portions occurs at just about the same time as the beginning of more rapid growth

in parts of the face, as previously described, and as demonstrated by West (97) and by Röse (75).

Growth of the Brain.—Data with regard to the size of the normal brain at different stages of development are meagre. Aside from this, there are many difficulties which arise from unavoidable inaccuracies in methods of sectioning and preparing specimens, and also from the fact that individual variations are great. Averages of brain weights are therefore of doubtful value.

It is generally agreed that the early years are years of very rapid gain in brain weight. There are no data, however, to show beyond question that a distinct nodality occurs at the beginning of the later childhood period. Curves for brain weights at different ages can only be said to suggest that this is true. Pfister is reported to have found that the brain weight at the end of the sixth year is not infrequently equal to that of the adult (71, p. 342). This is also observable in the tabulation of brain weights collected by Vierordt (90, pp. 36-37). Donaldson, in his study of the brain was led to conclude, largely on the basis of the curve for brain weights collected by Vierordt, that, ". . . . By the seventh year the encephalon has reached approximately its full weight, the subsequent increase being comparatively small . . ." (30, p. 104). We may say, therefore, not that brain weights show, but rather that they suggest a transition from rapid gain in gross weight to a different mode of development from the school age onward. This suggestion is strengthened by the fact that the rapid growth of the skull ceases at about the same time. Again, psychological investigations seem to show for this period a rapid development of muscular control, and the like, suggesting development along the line of better inner organization rather than by means of mere addition of material.

Development of the Eye.—Embryonically, the eye develops as a specialized portion of the brain. It is therefore interesting to note that there is some indication of its having attained approximately adult size at the same time with the brain. Stratz (86, a) has noted the relatively large size of the eye as compared to the small face of the child in the early years, due in part, of course, to the rather late development of the facial portions. The statement of Merkel would indicate that there is a further possible explanation. Without giving data, he says (55, Vol. 1, p. 256): "In connection with the development of the whole eye-ball, it occurs that the horizontal breadth of the iris is already reached in the sixth year of

life." Parallel to this fact—provided data may be found to support it as fact,—there occurs at about the school entrance age a transition in power to use the eye and also to control its movements.

An important factor is the power to employ binocular vision. In this is involved the ability to "fuse" the slightly different images from the two eyes and interpret them as one object. This begins in the first few weeks of life, and according to Miss Sayer (82), is usually complete about the sixth to ninth year of life. In learning to overcome the difficulty, the child has a tendency to "squint," but overcomes it after learning to use the eyes properly. From defects of vision, however, he may develop a permanent "squint." This is easily cured by means of the amblioscope if taken before the age of six, but otherwise it develops, as does stammering, into a pathological condition that is very difficult to cure. The statement of Dr. Cornell (23, p. 243) with regard to this condition is in agreement with that of Miss Sayer. Again, while largely dependent upon central brain structure, there should be mentioned in this connection the lack of power to retain visual imagery in case of those persons who become blinded earlier than the fifth to seventh year (49).

Here, again, phenomena which apparently involve both visual organs and visual brain centers would seem to suggest strongly that the closing years of earlier childhood constitute a time of change, both with respect to structural development and functioning.

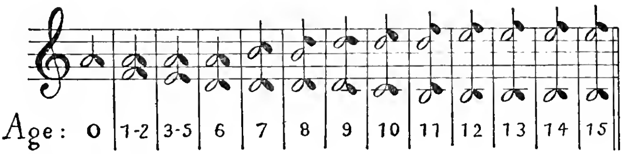
Larynx and Voice.—Vocal organs and vocal powers give evidence of a nodality of development at beginning of the later childhood period. Of the larynx Barth (6, p. 86) writes:

"In the first two years of life the growth of the larynx is very slight. With the active use of speech in the following years the growth progresses more rapidly. It appears, however, to be limited more to the muscles that move the vocal cords. From the sixth to the fourteenth year of life the growth of the larynx is almost stationary again, or, if it is present, is very slightly noticeable, strikingly and disproportionately less noticeable than the growth of the remaining organs of the body."

Cunningham's Anatomy makes a similar statement (28, p. 972):

"In the newly born child, the larynx, in comparison with the rest of the body, is somewhat large (———) and it continues to grow slowly and uniformly up to the sixth year of childhood. At this period there is a cessation of growth, which persists until puberty is reached, and then a stage of active growth supervenes."

Gutzmann's diagram of the averages for normal children of both sexes up to the age of fifteen (37, p. 51) indicates a rapid widening of the range of voice, beginning at the age of seven. Differentiation of the sexes is also shown at this time, the range for girls being wider than that for boys from this age onward. The diagram is as follows.



Neuro-muscular Control.—Differences in the power to control bodily organs indicate a transitional period at six or seven years. Speech development also gives such an indication. Apparently this period marks a stage of completion in speech coordinations, since infantile babble, if continued after this time, is usually considered pathological (22). Control of visual organs, as previously described, gives a similar indication. Unless corrected before this period, "squint" becomes permanent. Vocal power, on the other hand, as indicated by the range within which pure tones can be sung, shows a rapid increase from this time on (37). The two sexes also show a difference in breadth of range from this period onward, at least up to the pubescent years. Bryan's tests of precision in finger movements (14) showed that in both the "up" and "down" writing movements almost half the gain between the ages of six and sixteen was made between the ages of six and eight years. Halleck has stated, "The vital time for motor training is before the age of eight" (40, p. 835).

Pathological Conditions.—Some pathological conditions may be grouped together to show a relationship to this period of life. Stuttering, which differs somewhat from the infantile babble previously referred to, has been shown to be more prevalent at seven to eight years of age. Conradi (22) believes there is a causal connection between this and dentition. Jastrow (49) found among some 200 persons in institutions for the blind that those who had lost the power of sight previous to the age five to seven years did not retain visual imagery in their dreams in after years. Those blinded later than the age of seven, on the other hand, did retain visual imagery. Clouston, in his "Neuroses of Development" (21½), long ago observed that the age of seven or eight is a time when many neuropathic conditions are liable to

break out. In this connection again should be mentioned that "squint," also infantile babble are but natural when occurring previous to this age, while if lasting longer they seem to be so deeply grounded as to constitute pathological conditions.

These are by no means proofs, nor is the list complete, yet the suggestion is strong that after this period of life the physical organization is somewhat different from that which precedes.

Mental Development.—Adequate treatment of this topic would make this paper far too voluminous. We can touch it but briefly, stopping only for some general statements, chiefly concerning its relationship to our problem.

Early years have long been recognized as a time of sensory training, shorter attention span, shorter memory span, etc., but no sharp transition has been clearly shown. Mental tests are not yet sufficiently refined to grade accurately small steps of advancement. Individual variations are too great.

Though evidence to the contrary may be found, that there is a correlation of mental and physical development during school life has been indicated in a general way by such investigations as those of Porter (67), Smedley (84), Quirsfeld (72) and Crampton (26). Methods of grading mental advancement with reference to stage of physical development rather than chronological age at this period, however, have yet to be worked out. There is needed here much further investigation, on the individual plan, for the purpose of finding the degree of mental advancement that may be expected in a pupil of either sex who has reached a given stage in his or her physical development. The question arises as to whether such investigation might not show a characteristic of mental development corresponding to the transitions in the physical. Facts of brain growth, neuro-muscular control and the like suggest that this might be true.

Summary.—By way of summary we may generalize with regard to the preceding facts bearing on the question of nodality at the school entrance period as follows:

1. Disturbances of growth in height and weight have been noticed at this period but their nature is imperfectly understood.

2. Dentition shows distinctly a transition at this period, and because of close relationship to other phases of development suggests strongly that it is general in its nature.

3. Both skull and brain show a change in growth rate at about this time of life.

4. Growth of larynx and development of voice range indicate transition in these years.

5. The statements of some authorities with regard to growth of the eye and control of its movements suggest nodality in its development at this age.

6. Phenomena of muscular control, also facts regarding pathological conditions, give evidence of a change in physical organization after this period.

7. A clear-cut mental transition has not been shown, but tests have not related mental to physical stages of advancement. General correlations of mental and physical powers and facts regarding brain growth and muscular control suggest that tests relating these phases would indicate a transition here also.

On the basis of these facts it appears that the question regarding a transitional stage of development at the beginning of later childhood should be answered in the affirmative. The time at which these phenomena occur is of course only approximate, being based upon averages in most cases. The degree to which these changes are interdependent is also unknown. Whether they are all secondary to one basal, radical change, as for example dentition, or whether they represent a more general reorganization to which each is related cannot be stated. It seems probable that the latter is the case, although it is a problem that must be left open. It is certainly one that merits further investigation.

Comparative Development of the Sexes.

If, now, we give attention to the question of the comparative development of the two sexes at the school age, we are led to the consideration of a number of groups of data similar to those of the preceding section.

Occasional statements with regard to differences of the sexes at this early period of life have been made. Tyler (88, p. 139) thought girls of six begin to show signs of the precocity which characterizes later development. Röse mentioned differences of sex at time of second dentition (77, p. 555). Stratz (86 a) thought sex differences in bodily form first become evident at the age of six, after which girls show more grace of curve, boys more of angularity and strength. For the most part, however, it has been taken for granted that the development of the two sexes is the same until some time after this period of life is passed.

In an article published at a time when this study was near completion, Dr. Boas (9) made some comparisons of develop-

ment, particularly in dentition and ossification of the skeleton, which showed a greater advancement on the part of girls at this period. As he has stated, however, the number of data was limited, and the study rather of a preliminary nature. While his conclusions are partially correct, it may still be said that no extended comparison of facts has been made to decide the matter of comparative advancement of the physical development in the sexes at the beginning school period of life. It is our purpose here to attempt such a comparison.

Height.—Comparison of absolute height at any given time in the early years does not show any cause for a differentiation of the sexes. The same is true of comparisons where added increments are reckoned as percentages of previously attained height. A question arises, however, as to whether this is an adequate method for getting at the actual attainment for a given age. At maturity the male is considerably larger than the female. Nor do they reach maturity at the same time. If, then, our final comparison is to be one of unequals, comparisons previous to that time should not be on a basis of absolute equality, else erroneous conclusions will result. What we should ask is not, " Does the height of the boy equal that of the girl at a given age?" Rather should the question be, " What are the percentages of final, adult height reached in the two cases at a given age? "

Comparison by such a method has been attempted. In a preliminary reckoning, taking Dr. Boas' averages for children of larger American cities, as given by Burk (17, Table H.), the average height of boys at 6.5 years is 69.88% of the average at 15.5 years, while of girls it is 70.35%.

Results thus computated, on the basis of data from a number of extended investigations, are given in Table D. Except in the last three cases, where the references are indicated, these are on the basis of the corrected averages given in Burk's " Table A " (17). These last three are not the corrected averages. Since adult heights could not be secured from the tables, the average at 17.5 years has been chosen as representing post-pubescent height.

Since girls are nearer adult height at the age of 17.5 years than boys of equal age, it is evident that they are at a disadvantage in these comparisons. Yet in every case the indication is that they have attained a greater percentage of their post-pubescent height at the age of 6.5 years than boys of the same age. Comparisons with averages of adult height would be more accurate, but it is plain that they would also show greater differences of the percentages, thus making the girls appear still more advanced, relatively.

TABLE D.

PERCENTAGE OF POST-PUBESCENT HEIGHT ATTAINED AT SCHOOL ENTRANCE PERIOD.

Investigator	Age	Compared to	Percentage for Boys	Percentage for Girls
Bowditch.....(Boston).....	6.5 yrs.	17.5 yrs.	66.08	70.03
Porter........(St. Louis)....	"	"	66.	67.60
Peckham.....(Milwaukee)..	"	"	66.10	69.60
.............(Oakland)....	"	"	58.20	70.80
West.........(Worcester)...	"	"	66.90	69.70
Gilbert.......(New Haven).	"	"	67.06	70.70
Gilbert.......(Iowa).......	"	"	65.98	69.14
Key..........(Sweden).....	"	"	69.40	70.60
Anth. Com'n..(England)....	"	"	66.46	68.60
Quetelet......(Belgium)....	"	"	65.60	66.66
Pagliani......(Turin).......	"	"	64.60	65.90
Hertel........(Denmark)...	"	16.5 yrs.	68.11	70.40
[1] Smedley......(Chicago).....	"	17.5 yrs.	66.99	70.29
[2] Lange........(Germany)....	"	"	60.38	69.31
[3] Bobbitt.......(Phil. Is.)....	8	17	72.89	78.33

[1] See (84). [2] See (90, pp. 10-11). [3] See (12).

As a matter of interest, comparison of average heights of feeble-minded in nineteen institutions, as given by Goddard (35), was made, using ages six and twenty. Percentage of twenty-year height reached at the earlier age was, for males, 66.76, for females, 68.82.

Weight.—As in case of height, data for the average attainments of weight have not indicated any differences in the sexes preceding the pubescent period of growth. Both Porter (66) and Burk (17) noted a slight superiority of boys during the first few school years. Applying the method of comparisons just used in case of height, however, and using again the corrected averages from Burk's collection of data (17, Table E), we obtain the results presented in Table E.

While there is slight lack of uniformity in these results, in general it holds true that there is shown a superiority of girls in the amount of post-pubescent weight attained at the earlier age.

In case of both height and weight, therefore, the relative attainment of girls is shown to be slightly superior to that of boys at about the age of 6.5 years.

Skeletal Development.—Radiographic studies have shown that ossification of the skeleton proceeds more rapidly in girls than in boys during the early years. This is especially notice-

TABLE E.

PERCENTAGE OF POST-PUBESCENT WEIGHT ATTAINED AT SCHOOL ENTRANCE PERIOD.

Investigator	Age	Compared to	Percentage for Boys	Percentage for Girls
Bowditch.....(Boston).....	6.5 yrs.	17.5 yrs.	35.45	37.48
Porter........(St. Louis)....	"	"	35.58	35.94
..............(Oakland)....	"	"	36.14	38.99
Peckham.....(Milwaukee)..	"	"	34.35	38.04
West.........(Worcester)...	"	"	34.64	38.00
Gilbert.......(New Haven).	"	"	36.00	38.96
Gilbert.......(Iowa).......	"	"	32.82	34.38
Key..........(Sweden).....	7.5 yrs.	"	*39.60*	*39.53*
Hertel........(Denmark)...	6.5 yrs.	16.5 yrs.	*39.64*	*39.23*
Erismann.....(Moskow)....	"	"	34.83	42.37
Pagliani......(Turin).......	"	17.5 yrs.	31.66	34.57
Anth. Com'n..(England)....	"	"	33.91	36.10
Misawa.......(Japan)......	"	"	34.61	37.14

able in the carpal bones of the wrists and the epiphyses of the joints. Dr. Rotch makes this statement, but gives few data (80, p. 416). Pryor's studies, however, give data by which this seems to be clearly indicated (69), though their number is limited. He quotes a conclusion from a previous paper by himself as follows (69, p. 3): "The bones of the female ossify in advance of the male. This is measured first by days, then months, then years."

Choosing the trapesoid bone of the wrist as an example, we may note that he finds its time for ossification to be between the fourth and fifth year in the female, between the fifth and sixth year in the male (69).

Dentition.—Differences in the time of eruption of the teeth should again be emphasized at this point. Greater rapidity in the eruption of the teeth of girls was shown in case of each of the investigations referred to, beginning with the first molars and continuing up to the time of appearance of canines and second molars. The difference is by no means as great, however, at the first molar stage as Boas found (9, p. 815) from his limited collection of data. Röse's averages show the difference in time of first molars to be as small as one to two months. It should be emphasized again that the difference in eruption time of the teeth grows progressively greater with advancement of dentition. By the time the second molars appear, the difference in time between the

two sexes approximates the difference in time between their attainment of pubescence.

Growth of the Brain.—The limited number of data renders comparisons of brain weights for the two sexes very difficult. Only general indications may be noted. Curves constructed on the basis of Vierordt's data (30, p. 105) seem to indicate an earlier attainment of adult brain weight in females. This can be said to be little more than an indication, however, on account of the difficulties of method formerly referred to and the great variability in brain weights.

Neuro-Muscular Development.—The probability indicated by brain weights is in correspondence with that indicated by facts of muscular control. Hancock found in his swaying tests that girls were more steady in the early years than boys (41). Automatograph tests showed better lateral control of the arm, and tremograph tests showed greater control of finger movements among girls also. Observations of less definite tests again showed the superiority of girls in control of movements.

Bryan's tapping tests seem to be alone in their showing of better control on the part of boys. He says (14, p. 173) that differences are slight, but that within the narrow limits indicated there is a slight superiority of boys over girls.

Strength tests were compared by Burk (17) by a method similar to the one we have used for height and weight. From the data of Porter, Roberts and Gilbert he found percentages indicating that boys had attained 1/5 their sixteen-year strength at the age of six years, 1/4 from six to eleven. Girls had gained a greater percentage at six, and from this on their acquirement was more rapid than that of boys.

Gesell noted that boys as a class show greater tendency toward uncoordinated writing as early as the first grade and up through the high school (33).

In this connection should be mentioned again that, beginning with the age of seven, the range within which pure tones can be sung is wider for girls than for boys.

Stuttering, which begins most often in the early years, has been found in a number of investigations to be more prevalent among boys (22, p. 361). Various ratios for the sexes have been reported. Conradi reports also that girls learn to talk earlier than boys (22, p. 363).

With the exception of the tapping tests, all the indications of power of control here enumerated show superiority in girls.

Summary.—On the basis of the data here presented it seems fair to conclude that the physical development of girls

is relatively more advanced than that of boys at the age of five or six or thereabouts. On the average they have then attained a greater percentage of their post-pubescent height, a greater percentage of their post-pubescent weight, their skeletal development is more advanced, and their dentition has progressed further. Aside from this there is a strong suggestion that a greater percentage of adult brain weight has been attained by them, and this is supported by the fact that most data available show a more advanced power of neuromuscular control. How great the difference in general physical development is a matter to be determined by further investigation.

Discussion, Pedagogical Suggestions, and Summary

So far, the aim has been to find solutions for our two main problems. For the first we may say that, while not proved, a great mass of data indicate a transition in physical development at the period of usual school entrance. Regarding the second we may say that greater advancement in the physical development of girls at this time is pretty clearly shown.

The solution or partial solution of these two problems suggests a number of others. If this is a transitional period, what is its fundamental nature? Is the transition general or due to a single factor, as dentition? That it is the former seems to be the case, but it is still an open problem. In case the transition is not of a general, fundamental nature, then a whole series of problems regarding the relationship of these several transitional phenomena arise. For example, is rapidity of dentition to be correlated with rapidity of skeletal ossification, as Holt (45) has stated is the case in infancy? Are disturbances of growth in height and weight noted at this period due to conditions of dentition or do they occur regardless of it?

The correlation of mental with physical development at this period is a problem which those working with mental tests cannot afford to neglect. Granted a degree of physical and mental correlation, and that this period is a transitional one for physical development, then the whole question of qualification for school entrance is thrown open anew. The problem is still further complicated by the fact of great variability shown in the developmental factors at this time.

In view of their close relationship to other phases of physical development, and in the absence of definite methods of grading, the question arises as to whether the time of appearance of the first molars could not be cited as a point before which school duties should not be imposed.

The differences of the sexes at this period also suggest some important problems. Recalling that the female reaches maturity some three years earlier than the male—or nearly so—and that she reaches the pubescent stage almost two years earlier, on the average, the fact that she has progressed further at the school entrance age is to be expected. The question arises here, however, as to how early the differentiation of the sexes actually begins. Since differences in the averages of absolute measurements are noticeable at birth, and in view of the popular opinion that the prenatal period is shorter for females than for males, one is tempted to raise the question as to whether differentiation does not actually begin before birth.

The problem of the amount of difference between the sexes comes up, and also the further one of working out a method sufficiently refined to measure them. The question as to what this difference signifies for the pedagogy of this period of life is an extremely important one.

The preceding facts and conclusions form the basis for some further conclusions and suggestions for the hygiene and pedagogy of the early years of childhood.

We have shown that boys and girls of equal age are not equally advanced physically at the school entrance period of life. We have presented a mass of evidence in support of the conclusion that this is a transitional period in the physical development, referring to the great individual variability, as indicated by dentition, skeletal development, etc. Associating these facts with the indications of a correlation between mental and physical development, the need of a physiological grading for entrance to school becomes strikingly evident. Granted a proper grading for entrance on this basis, the grief and the expense of "repeaters" up through the grades would be tremendously lessened. School entrance should be on the basis of the fitness of the individual, not on the basis merely of his chronological age.

Again, the rapid growth, the ease with which the delicate balance of the organism may be overthrown, the lasting detrimental results following the wrong "inclination of the twig," all suggest that the thing of supreme importance in these early years is rather health and development than formal school work. The paramount importance of habits of health is shown over and over again in case of the teeth. Lack of the habit of cleanliness of the teeth is followed by caries, loss of bicuspids or all important first molars, with probably ill-fitting permanent dentures, deformed facial features and injury to health. Habits of thumb-sucking, mouth-breathing,

and the like, may cause malocclusion and abnormal growth of jaws and related facial parts. Good permanent tooth crowns are largely dependent upon fresh air, exercise and good nourishment throughout the first five or six years of life. Attention to all these things should be first until after the organization of the childish body is more nearly complete.

The eyes are unfit for close visual work until after the transitional period.

Adenoids left uncared for in these early years are liable to cause disturbances of development. According to Yearsley (104) the time to have them removed is after six months and before six years of age.

Enlargements of the tonsils, with decreased power to resist invasions of micro-organisms, accompanies eruption of the first molars, in many cases (100, p. 13). Until after this time, no child should be confined to the school room where his chances of exposure to infectious disease germs are increased.

In view of all these things, this survey would be worth while, even though it did no other thing, could it portray in its true light the importance of all the years of earlier childhood for the normal, healthy physical development of the child.

From a different viewpoint another suggestion is in place. Could "types" be agreed upon for use in comparisons of stature, and like physical characteristics, similar to these used in anthropometry, much more accurate knowledge of development might be gained. Grouping of material according to types, combined with comparisons of relative advancement, such as we have used above, should lead to more satisfactory results in indicating stages of development.

Final Summary.

The main conclusions to which the facts presented in this thesis point are:

1. That there is a mass of evidence indicating a transition in the physical development of the child at the period of usual school entrance.

2. That there is evidence to show that girls are on the average more advanced in their physical development at this period.

3. That requirements for entrance to school based on stage of progress in physiological development, or physiological age, would be far superior to a requirement taking account of chronological age only.

4. That in the application of physical measurements for the purpose of finding degree of progress in physical development, a method indicating the percentage of adult size attained at a given age is superior to a method comparing absolute data directly.

5. That the hygiene and pedagogy of this period are of prime importance for the future development and welfare of the individual.

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